Goddard Program for Measurement of Carbon Dioxide using a Broadband LIDAR.

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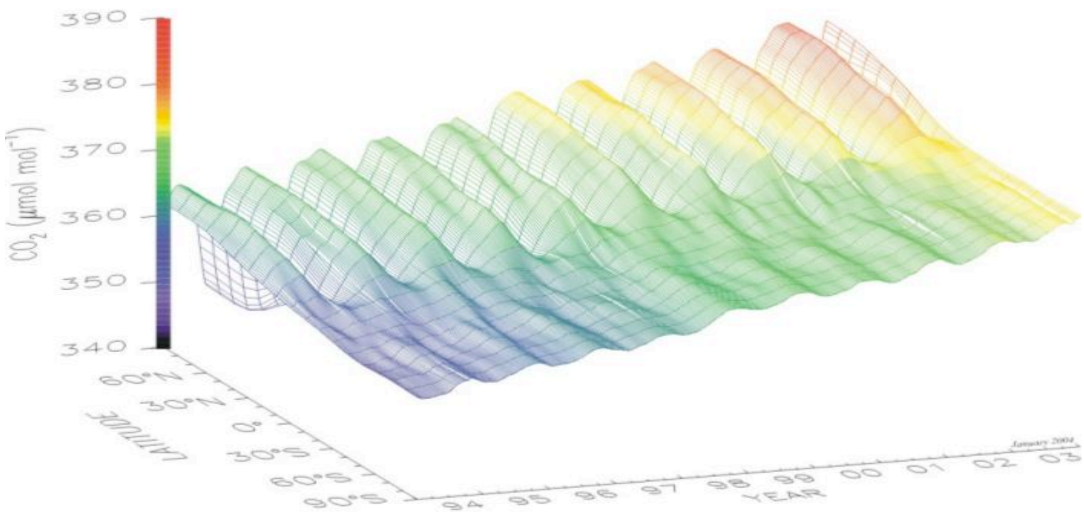
Earth Science Technology Forum 2010

OUTLINE OF TALK

I. Need for CO_2 Measurements
II. Why Broadband LIDAR?
III. How Does it Work?
IV. What Next?



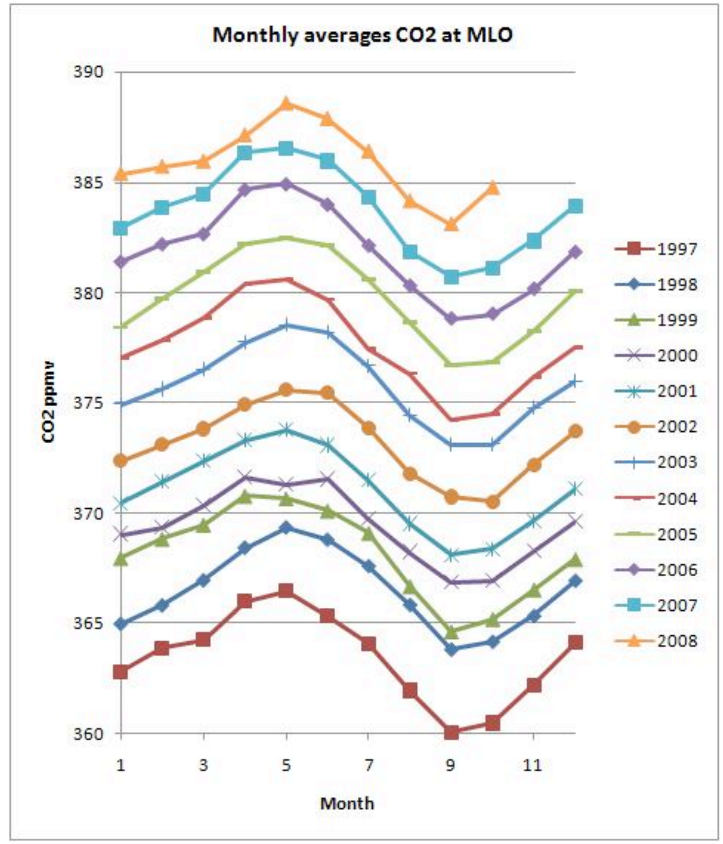
Three dimensional representation of the latitudinal distribution of atmospheric carbon dioxide in the marine boundary layer. Data from the NOAA CMDL cooperative air sampling network were used. The surface represents data smoothed in time and latitude. Principal investigators: Pieter Tans and Thomas Conway, NOAA CMDL Carbon Cycle Greenhouse Gases, Boulder, Colorado, (303) 497-6678 (pieter.tans@noaa.gov, http://www.cmdl.noaa.gov/ccgg).

THE MISSING SINK

There is great need for global high spatial- and temporal-resolution remote sensing of atmospheric CO_2 concentration for global and regional studies of the carbon cycle and thus for better resolving the linkage between global warming and anthropogenic CO_2 emissions. The biggest challenge for CO_2 remote sensing is to achieve high measurement precision (~ 1 ppmv) so that such a measurement is valuable in reducing uncertainties about carbon sources and sinks.

Of anthropogenic CO_2 emitted to date, ~ 30% can not be accounted for - the "unknown sink"

Some of the missing CO_2 has been incorporated by increased growth of forests, especially in North America; increased amounts of phytoplankton in the oceans; uptake by desert soils (mechanism as yet unknown).



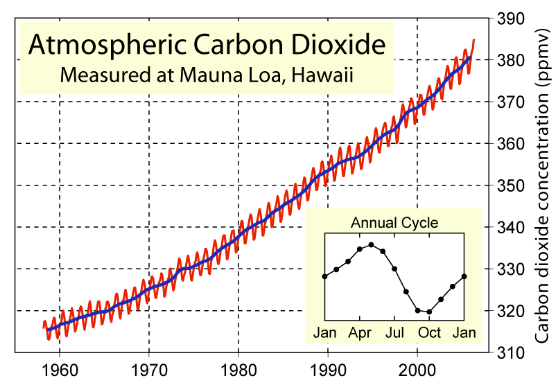
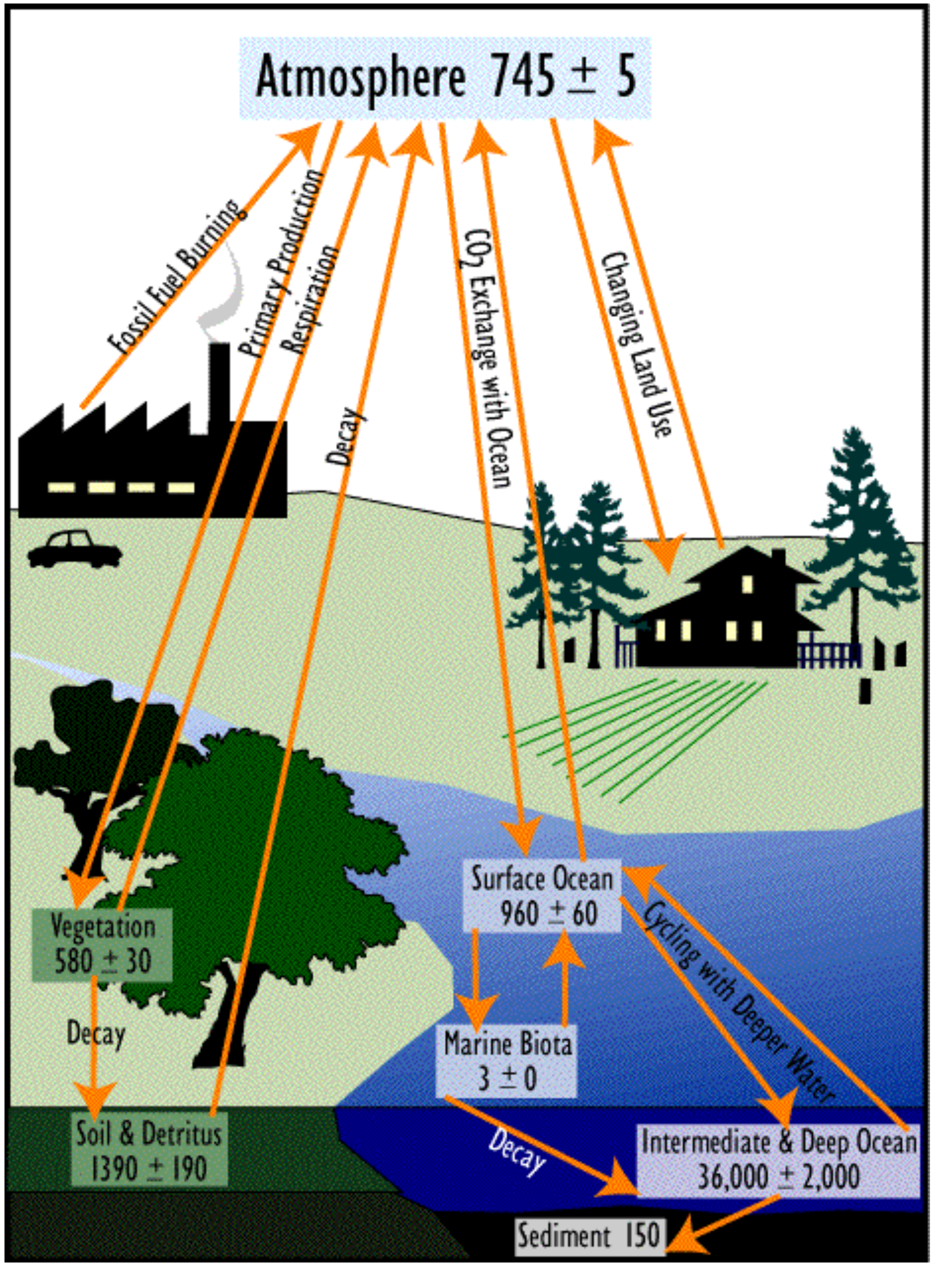


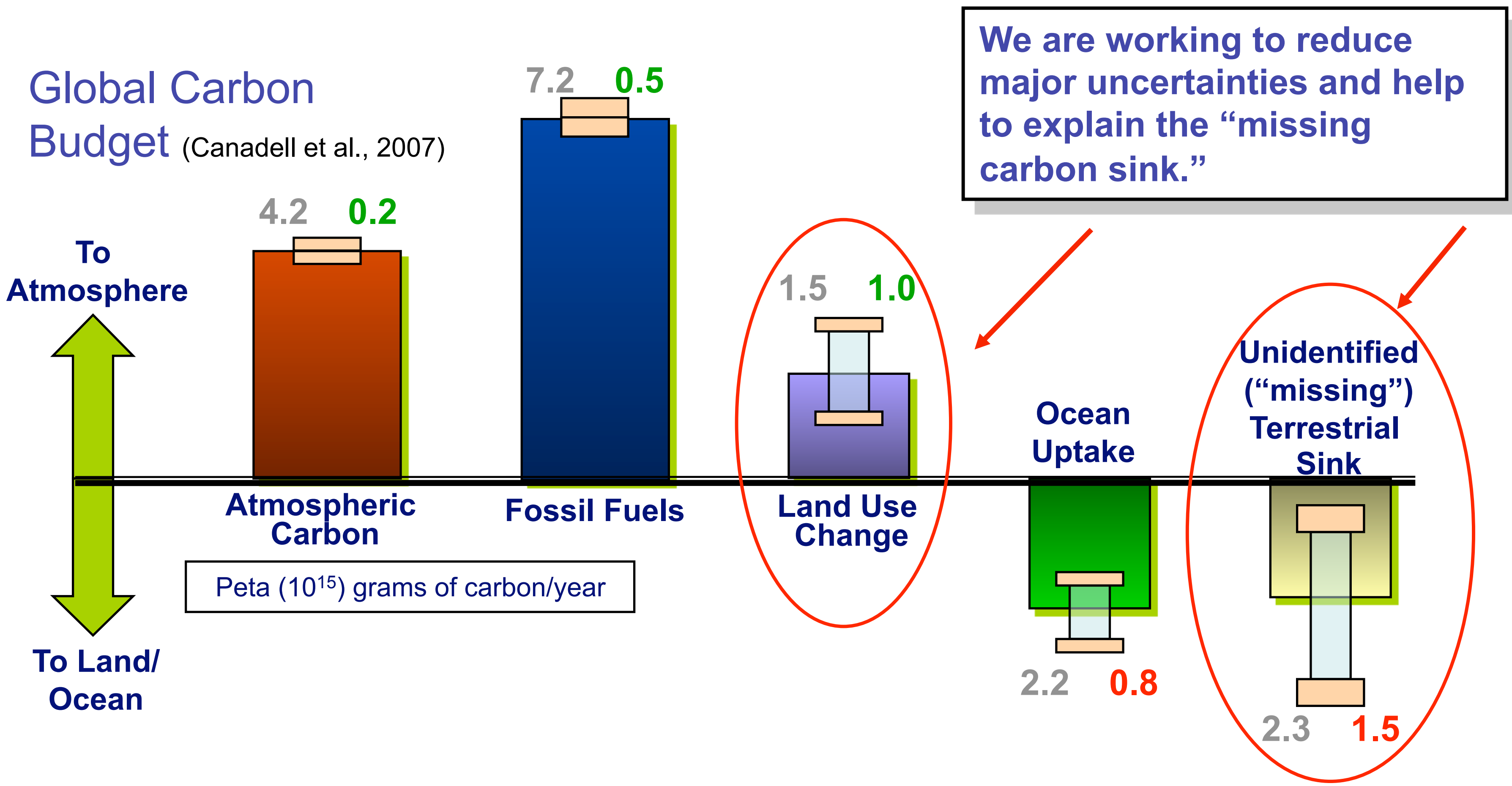
Image wwmm.ch.cam.ac.uk



Atmosphere 745 ± 5
Fossil Fuel Burning
Primary Production
Respiration
Decay
CO_2 Exchange with Ocean
Changing Land Use
Surface Ocean
960 ± 60
Vegetation
580 ± 30
Decay
Cycling with Deeper Water
Marine Biota
3 ± 0
Soil & Detritus
1390 ± 190
Decay
Intermediate & Deep Ocean
36,000 ± 2,000
Sediment 150

Largest remaining uncertainties about the Earth's carbon budget are in its terrestrial components.

Carbon Budget



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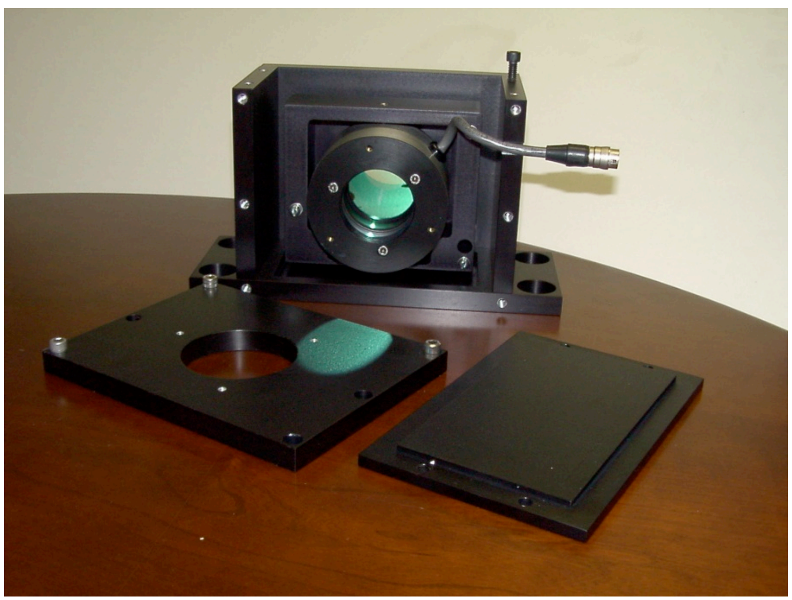
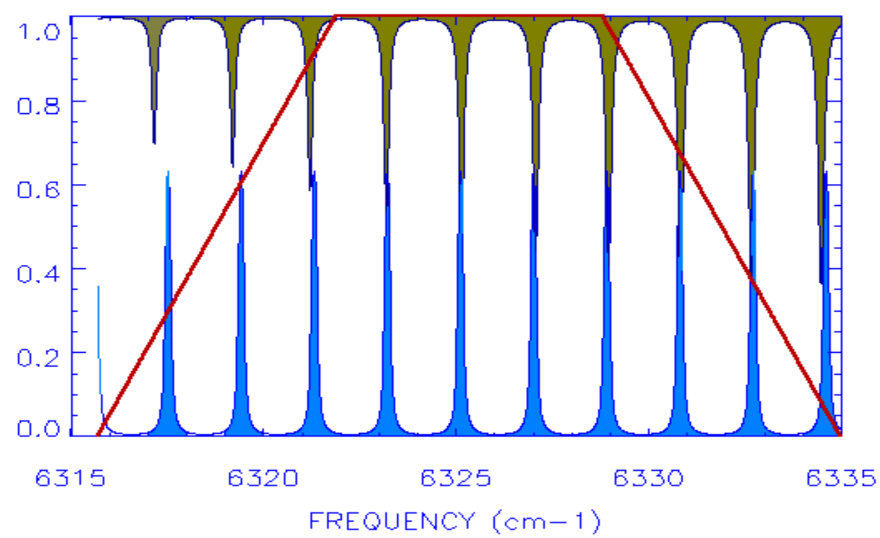
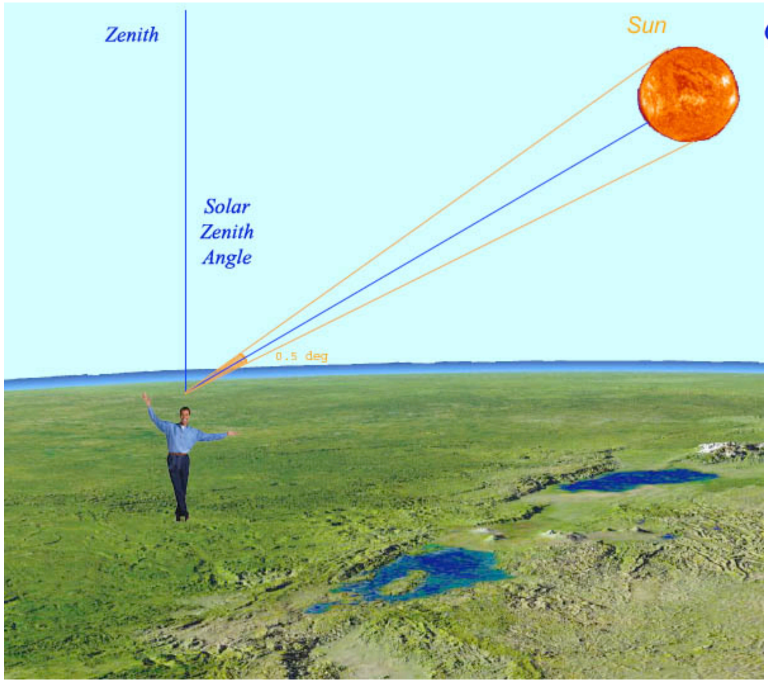


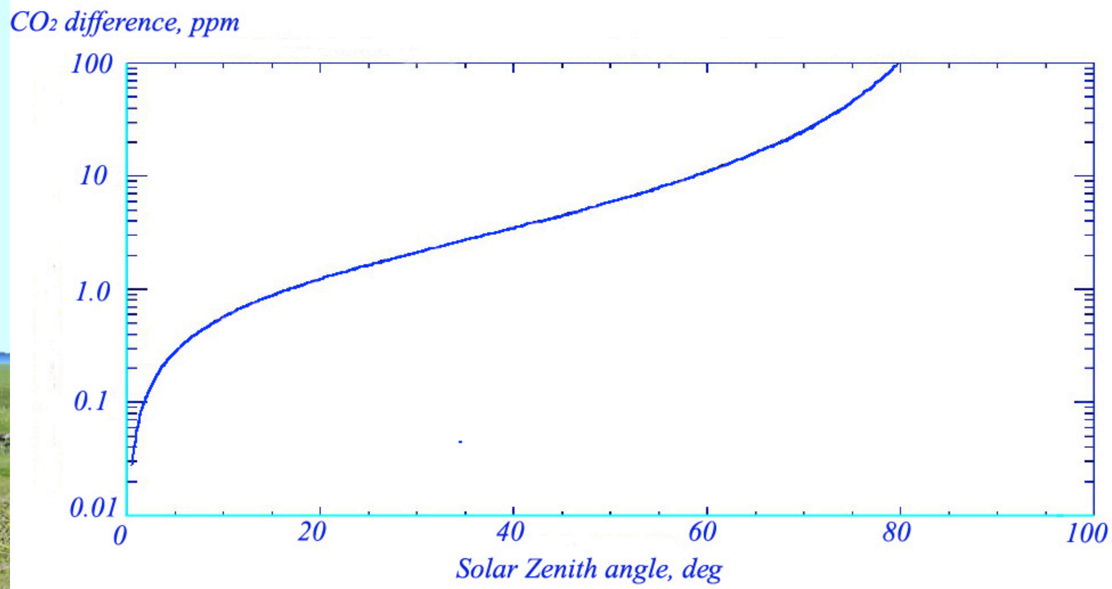


The Path Length Problem I

If the entire atmospheric column could be compressed into a box with a constant pressure of one atmosphere the box would be roughly seven kilometers thick. A change in the column by 1 part in 400 then would represent a change in the box thickness of 7000/400=17.5 meters. This means that a change in the optical path of light that is being used to measure the CO_2 column as small as 17.5 meters would produce a change in the column measurement of about 1ppm—the desired measurement precision. Clearly changes in terrain can produce path length deviations much larger than this so a successful CO_2 measurement must include some method of determining this path length. Simultaneous measurement of the O_2 column has been suggested since this also corrects for changes arising from meteorology. Atmospheric scattering can produce path length changes much larger than 17.5m and depending on the distribution of scattering particles and the elevation of the sun the changes can be either positive or negative.

The Path Length Problem II





For passive sensors using sunlight just the difference in the path from the top of the sun to the bottom of the sun can greatly exceed the 1 ppm requirement for precision.

THE ASCENDS MISSION

- The goal of Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS) mission is to significantly enhance the understanding of the role of CO_2 in the global carbon cycle.

- The National Academy of Sciences recommended in its decadal survey that NASA put in orbit a CO_2 lidar to satisfy this long standing need.

- Existing passive sensors suffer from two shortcomings.
  - Their measurement precision can be compromised by the path length uncertainties arising from scattering within the atmosphere.
  - Also passive sensors using sunlight cannot observe the column at night.

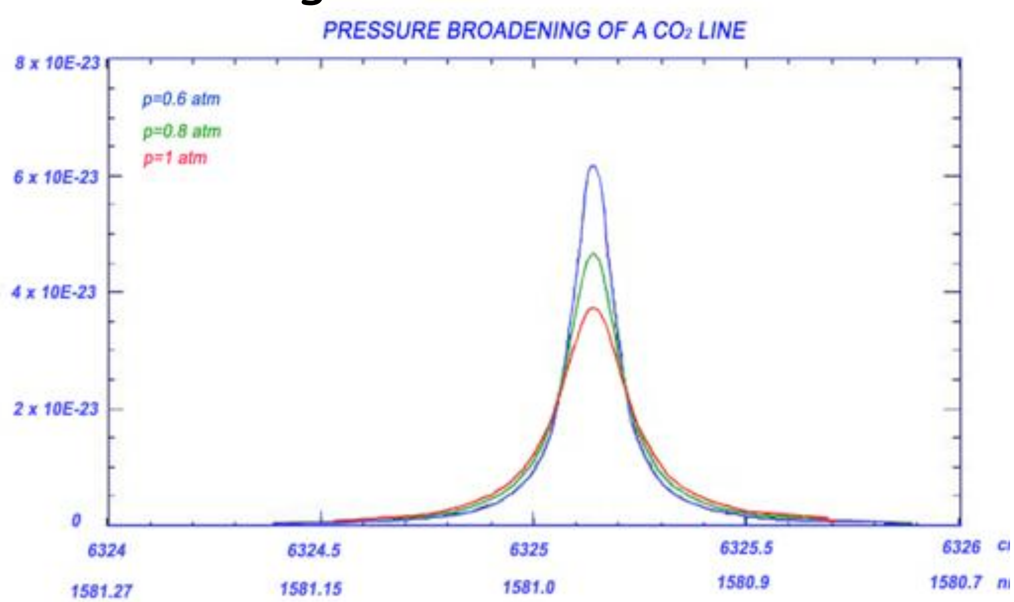
- Both of these difficulties can be ameliorated by lidar techniques.

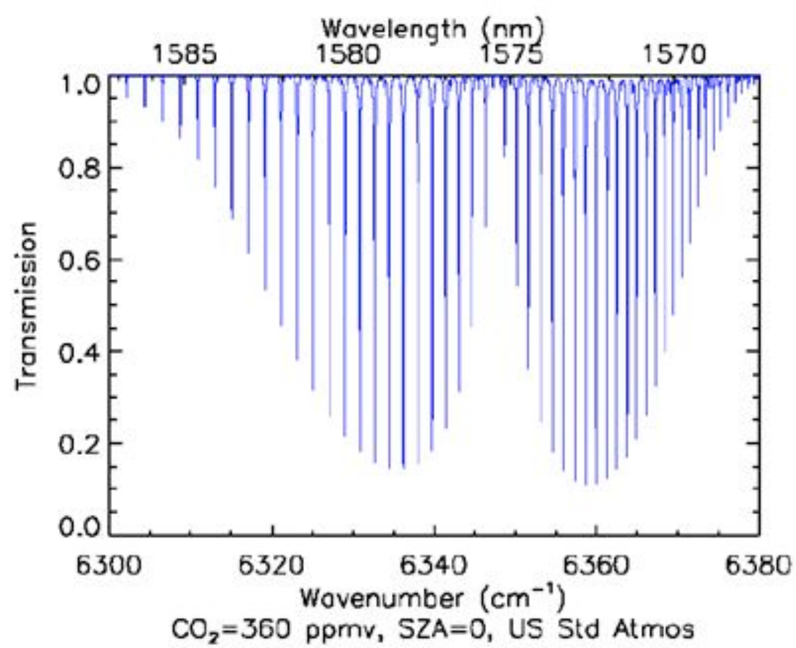
LIDAR SYSTEMS

- Lidar systems present Global measurement of carbon dioxide column with the aim of discovering and quantifying unknown sources and sinks has been a high priority for the last decade. These systems have their own set of problems however.
  - Temperature changes in the atmosphere alter the cross section for individual CO_2 absorption features.
  - Different atmospheric pressures encountered passing through the atmosphere broaden the absorption lines.
- Currently proposed lidars require multiple lasers operating at multiple wavelengths simultaneously in order to untangle these effects.

SPECTROSCOPY-PRESSURE EFFECTS

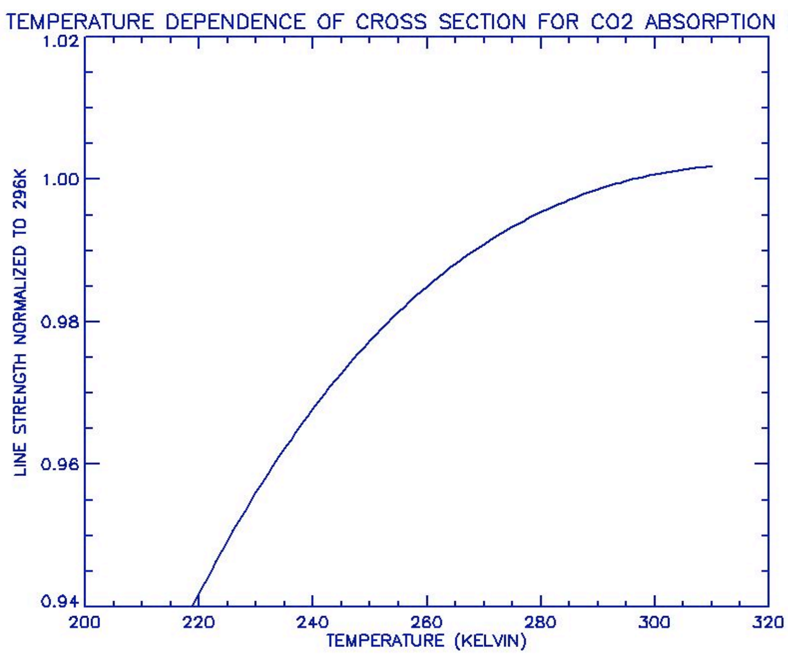
At the top of the atmosphere the width of a spectral line is dominated by the Doppler effect. Proceeding lower into the atmosphere collisional (pressure) broadening begins to manifest itself to a greater and greater extent. A shift in the center frequency also occurs as the result of collisions. There is only a minimal contribution to the absorption in the wing from the upper atmospheric CO_2 the effect of a surface source or sink will be a larger perturbation on the overall column absorption at these wavelengths.

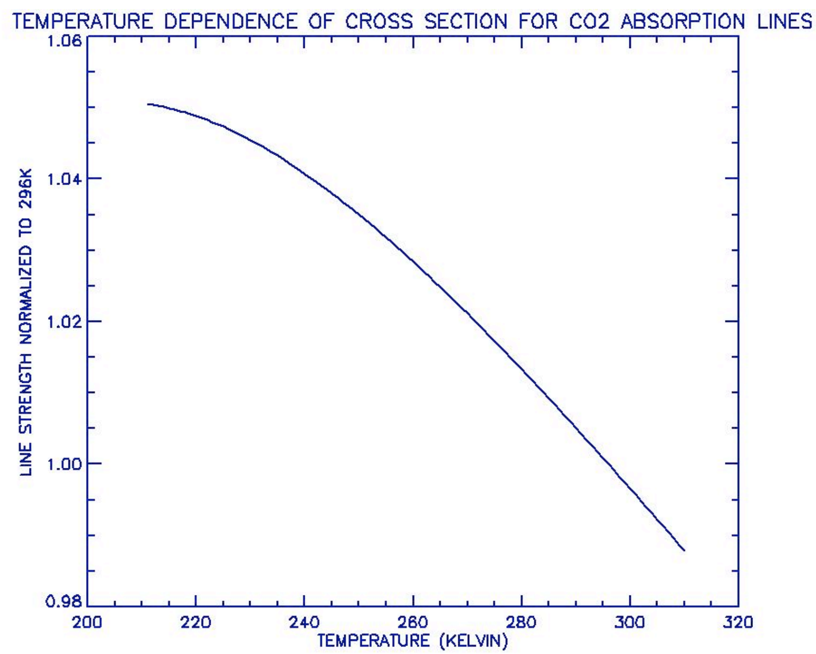




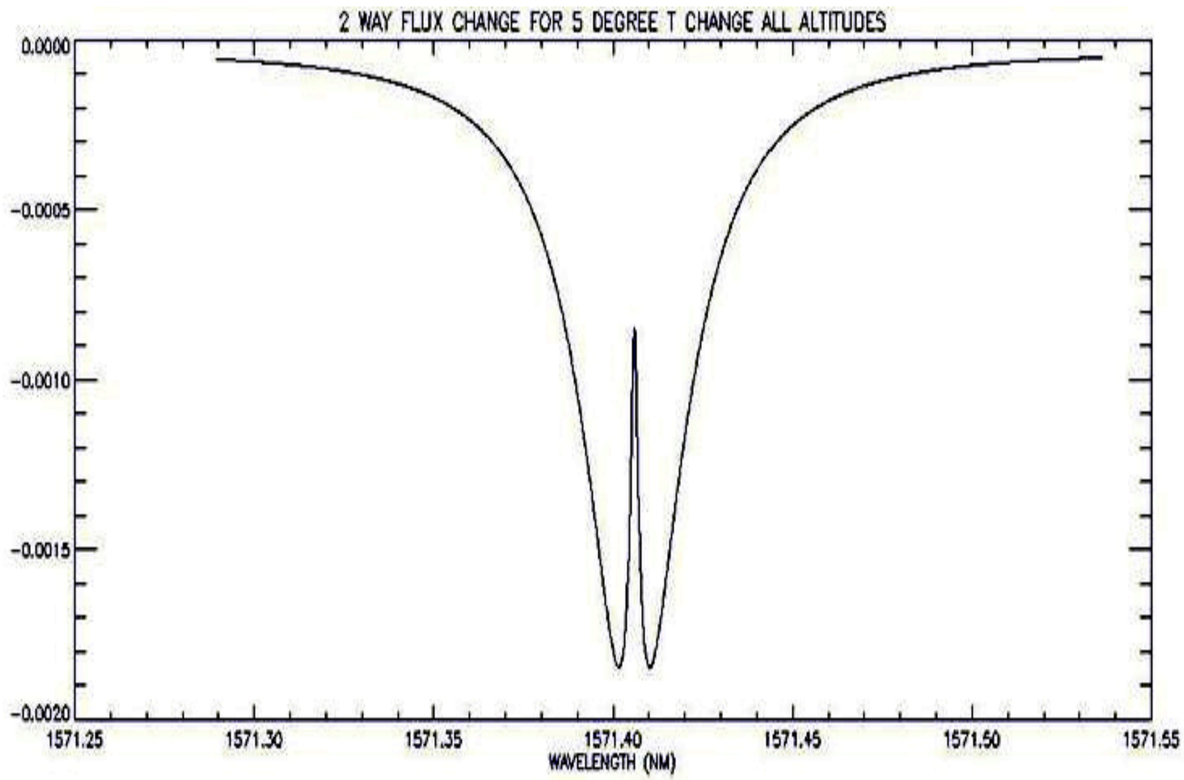
SPECTROSCOPY-TEMPERATURE EFFECTS

The line strengths change with the temperature of the atmosphere This can introduce errors in the column as large as 1ppm for a 2 degree K change in temperature. This means that using a single absorption line and relying on meteorological measurements or models to provide the temperature correction may not suffice for the CO_2 column measurement.

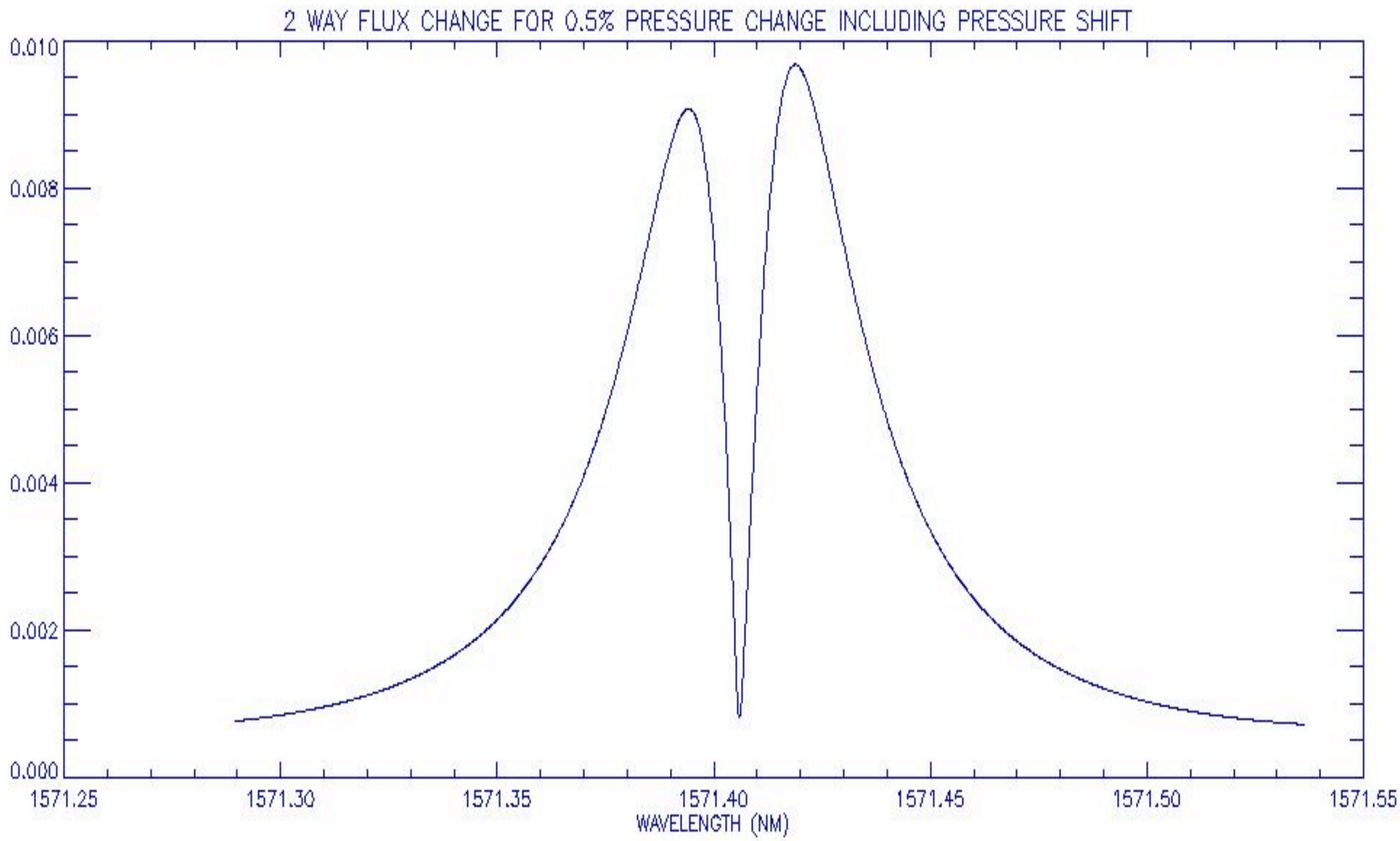




SPECTROSCOPY-TEMPERATURE EFFECTS



PRESSURE AFFECTS DIFFERENT PARTS OF AN ABSORPTION LINE DIFFERENTLY



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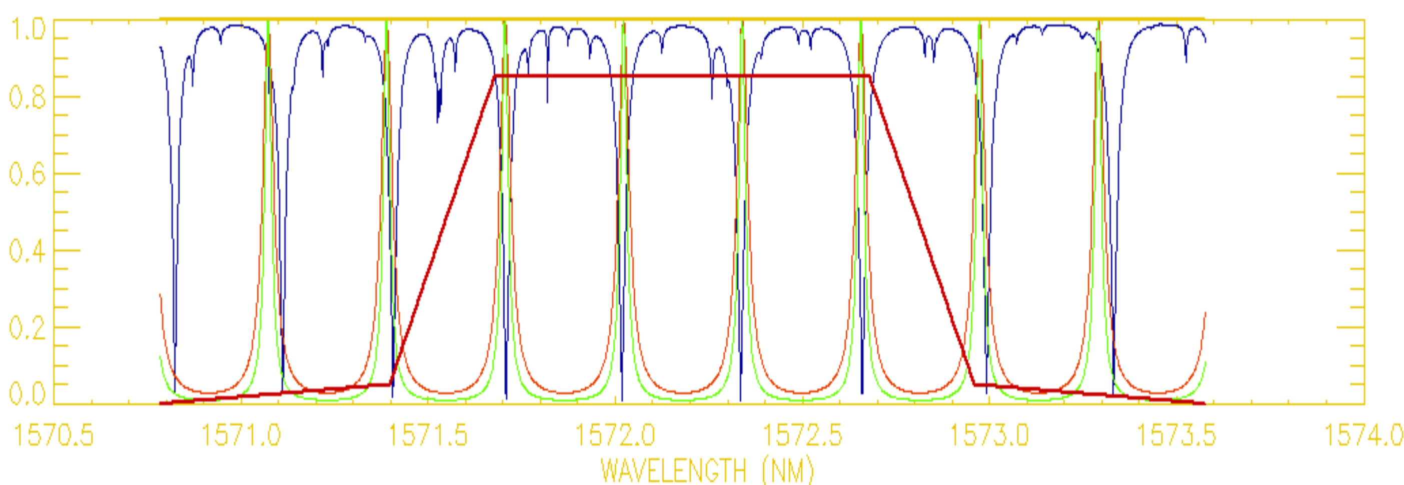

Fabry-Perot Radiometers

Fabry-Perot based radiometers exhibit exquisite sensitivity,
They are small, simple, rugged, cheap, and versatile.
They have the potential to measure different gas species using different platforms – ground based, airborne, satellite.

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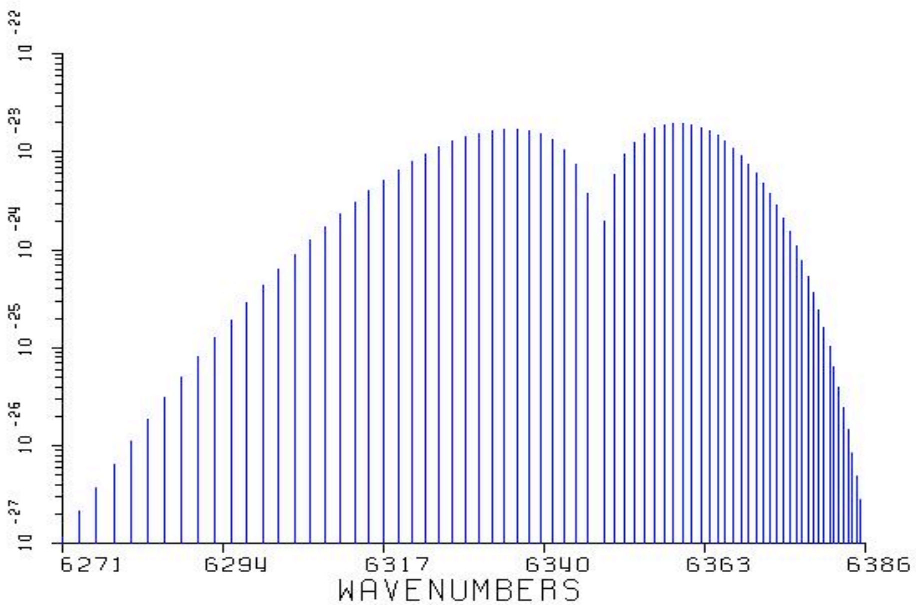
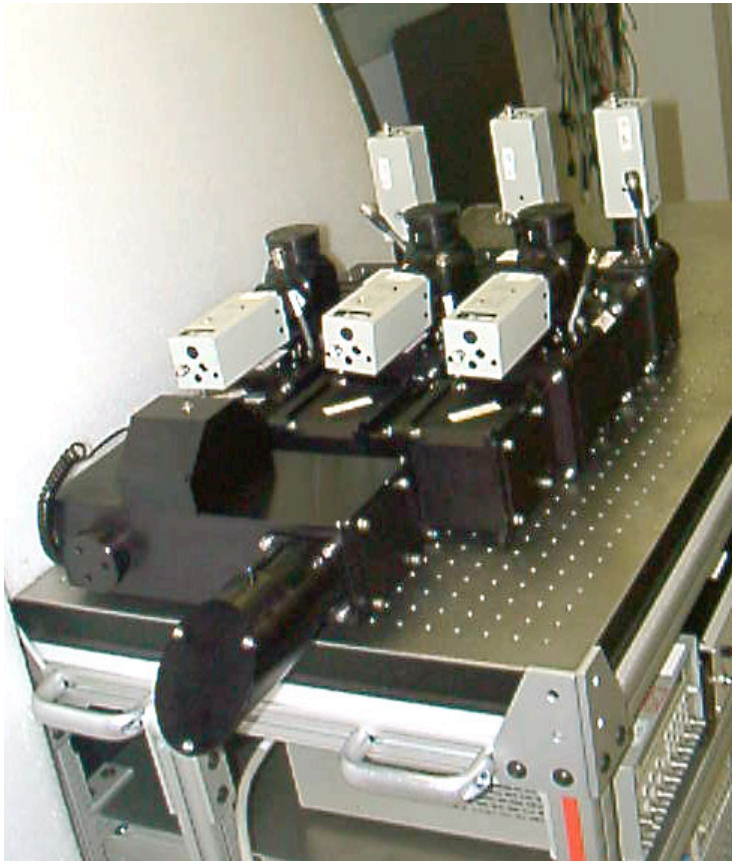
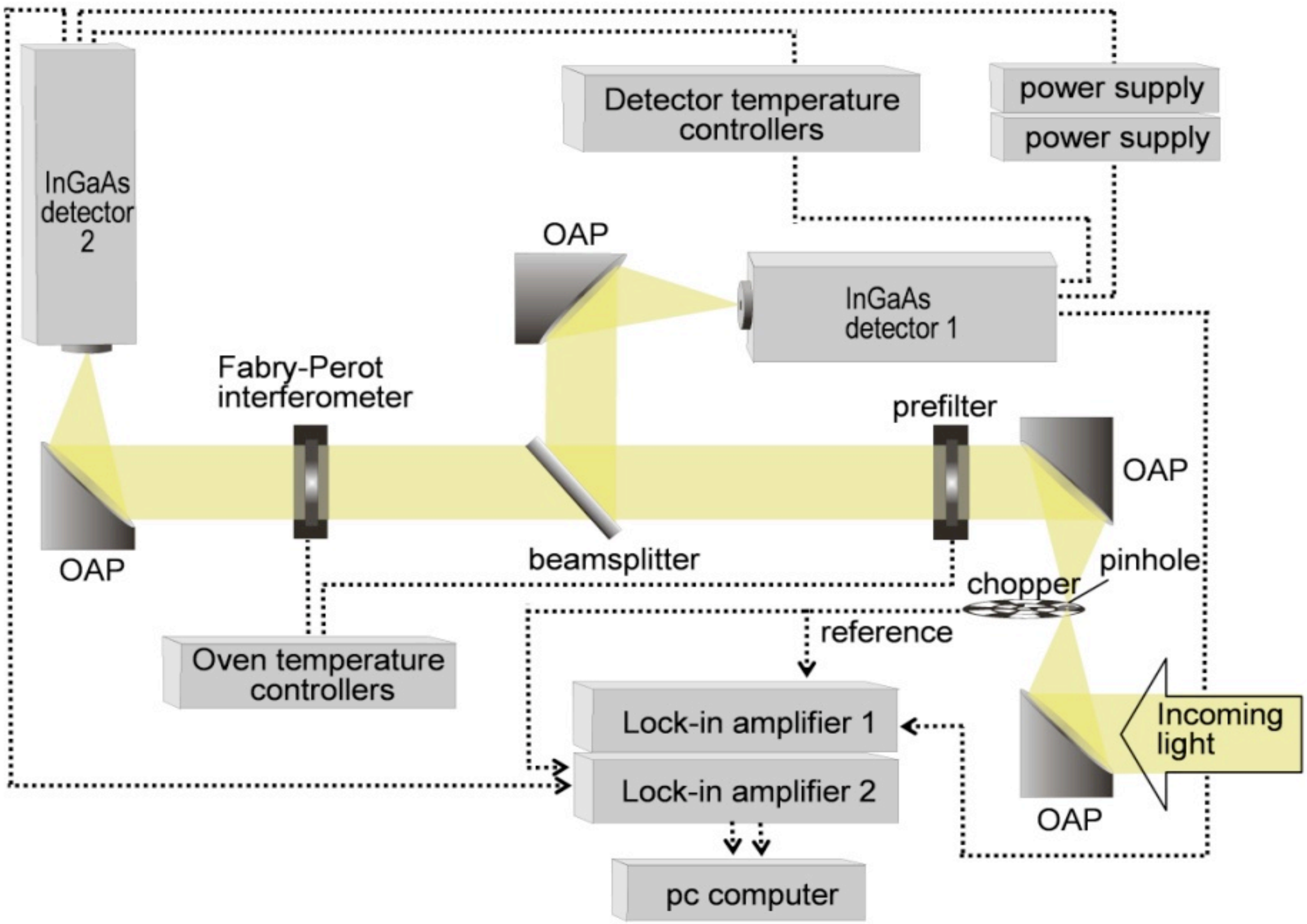
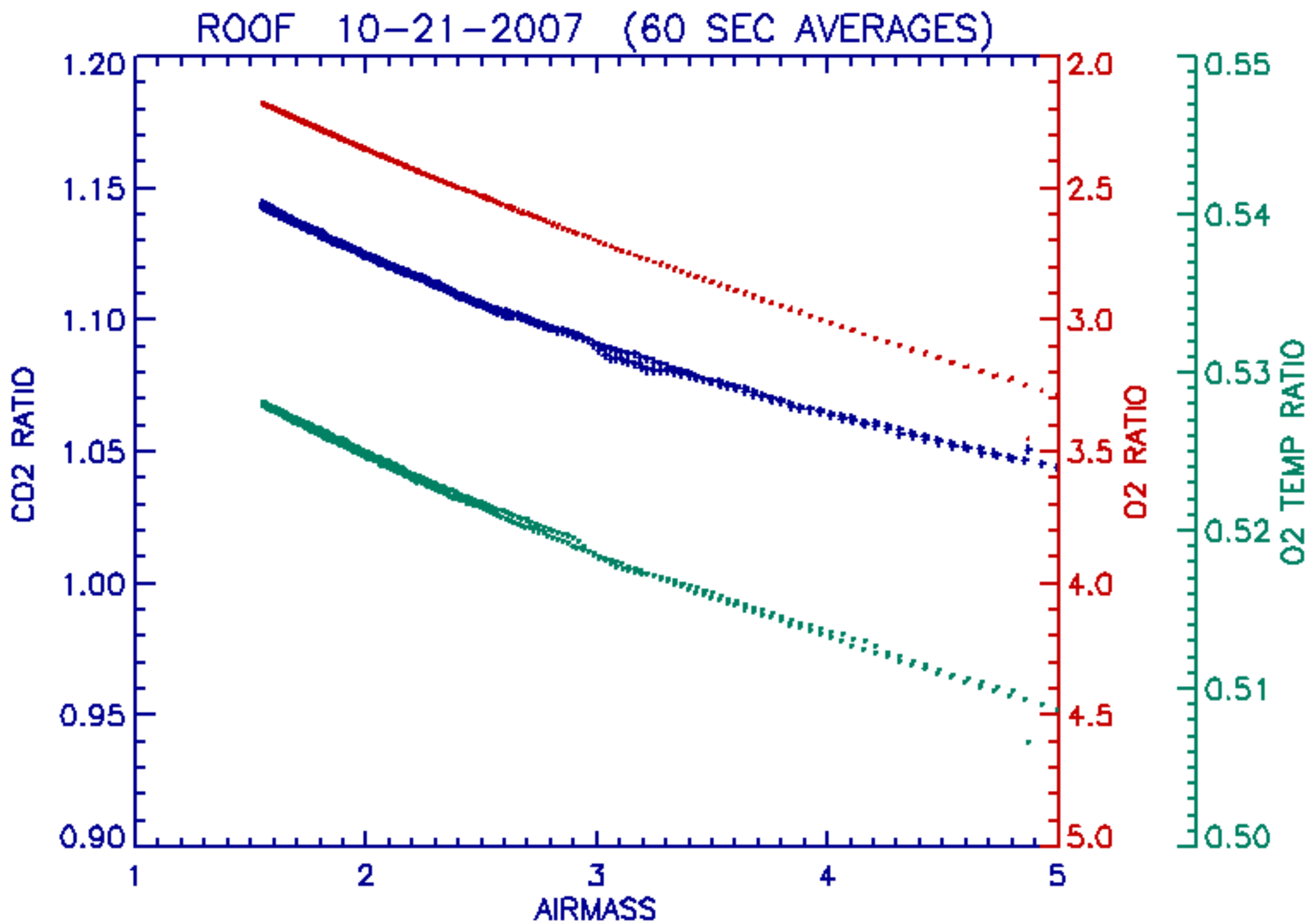




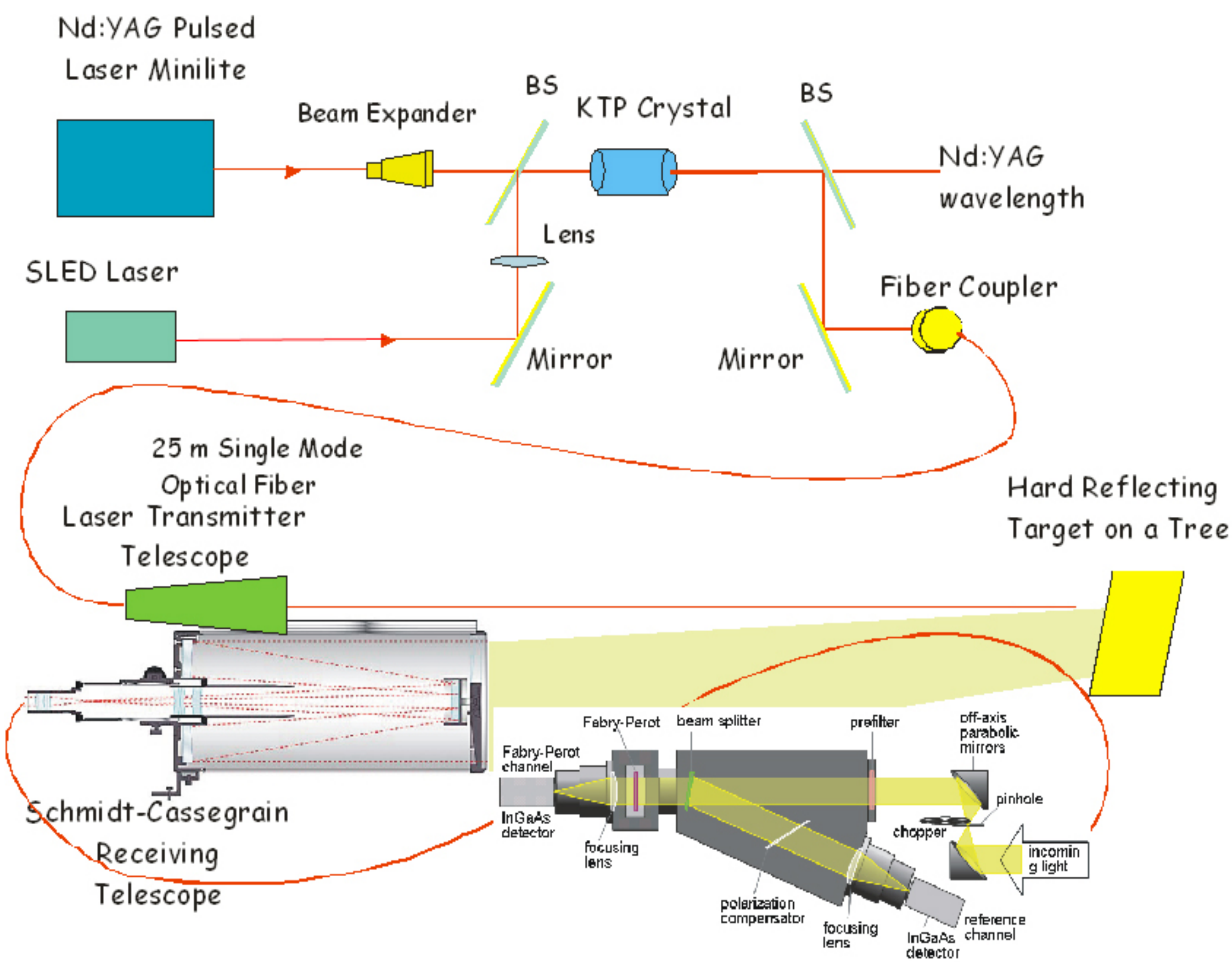
Schematic of one channel of the FP radiometer:



FP/REF RATIO V AIRMASS



OVERVIEW OF 1.57 MICRON BROADBAND SYSTEM



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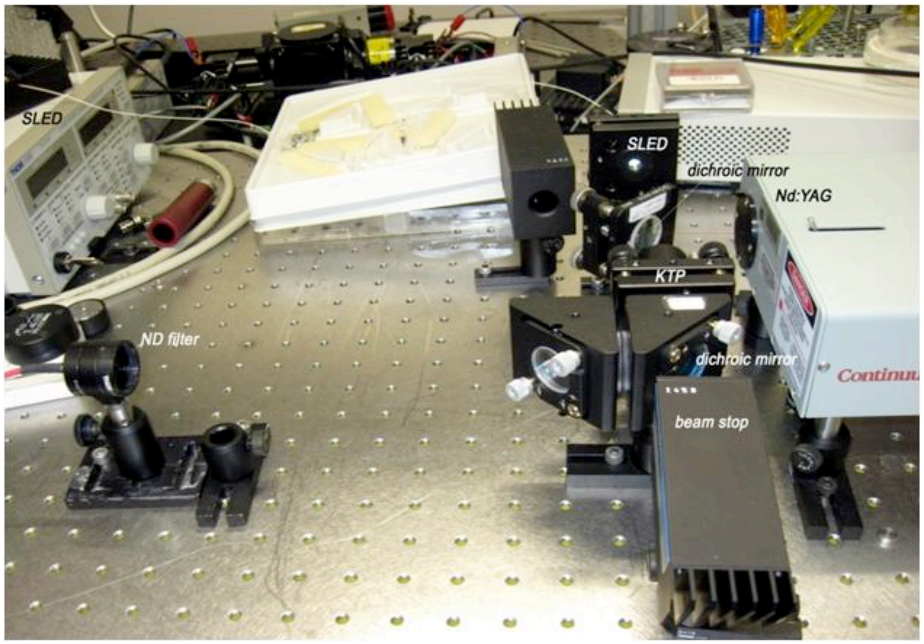
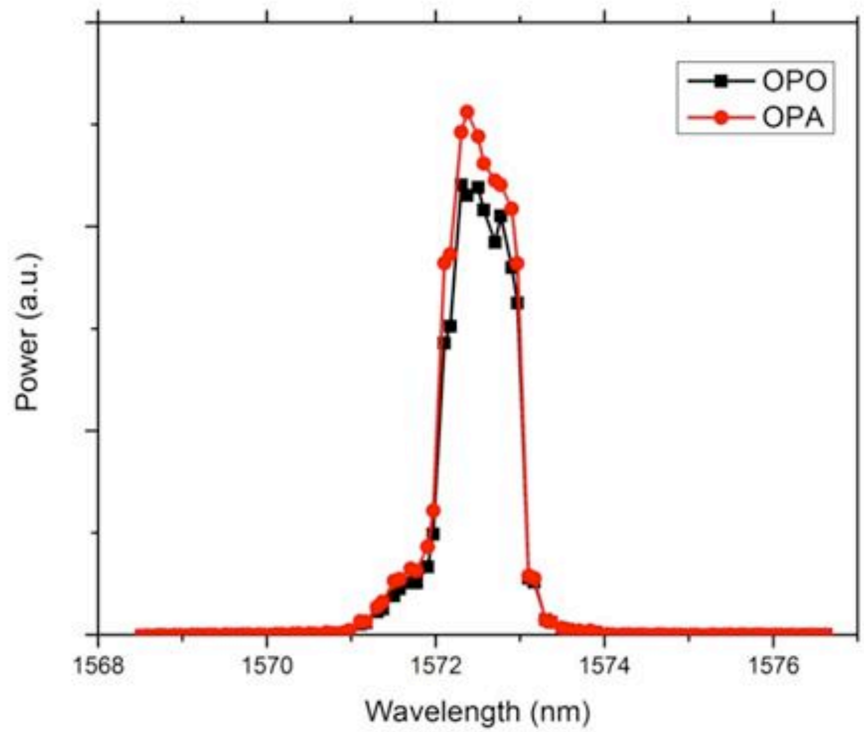
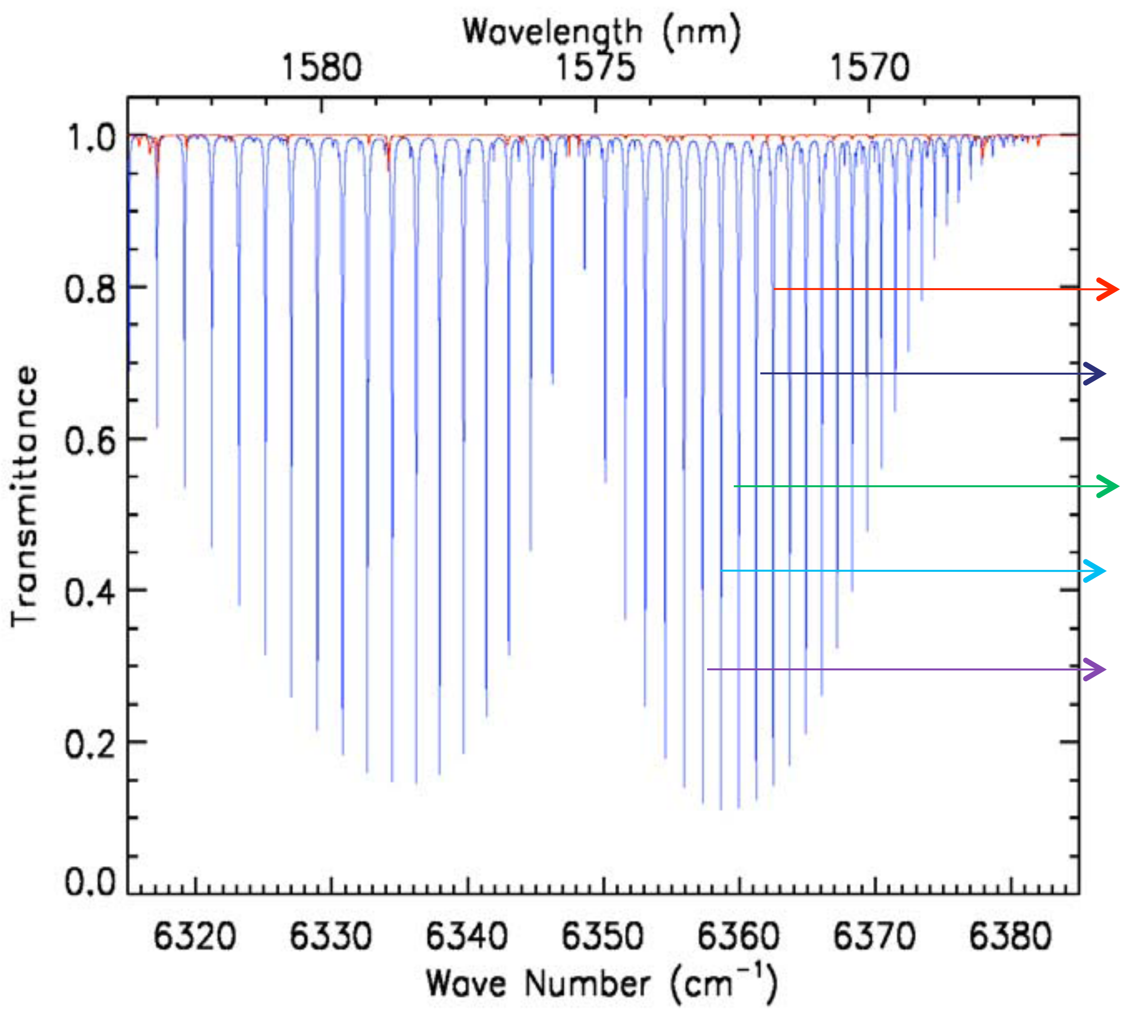
OPO/OPA BROADBAND SOURCE





220 mW AVERAGE POWER OUT TO DATE.



There are CO_2 absorption lines located at

1571.7,

1572.0,

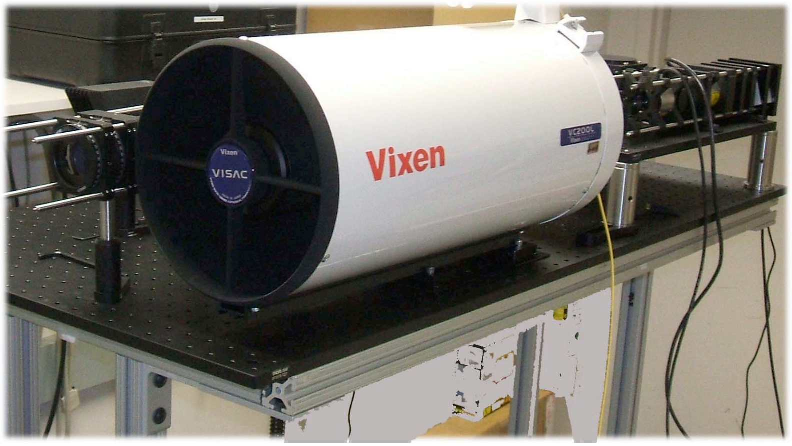
1572.3,

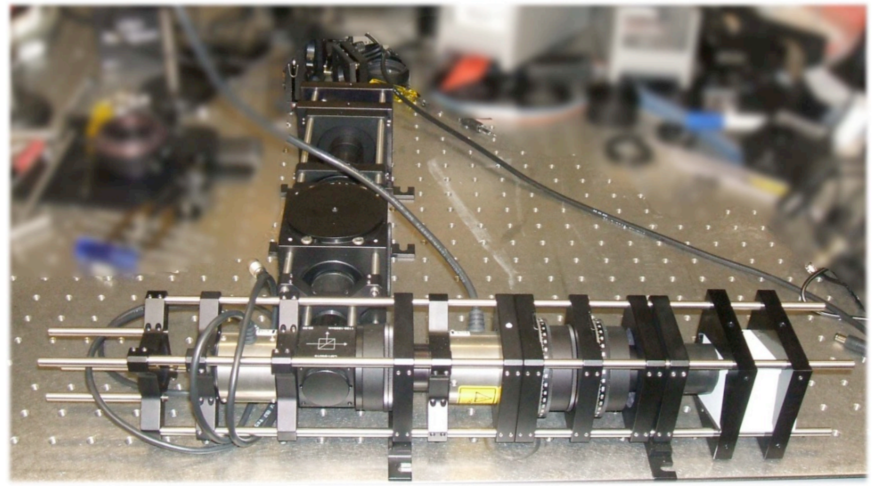
1572.65,

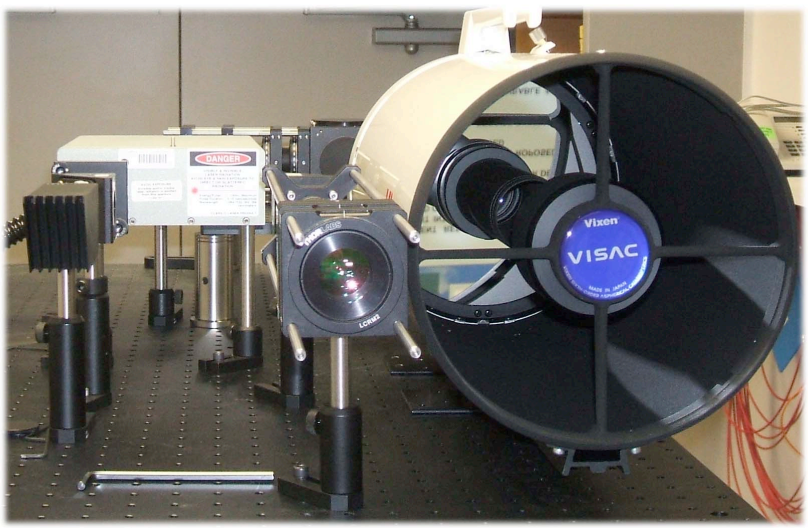
and 1573.0 nm

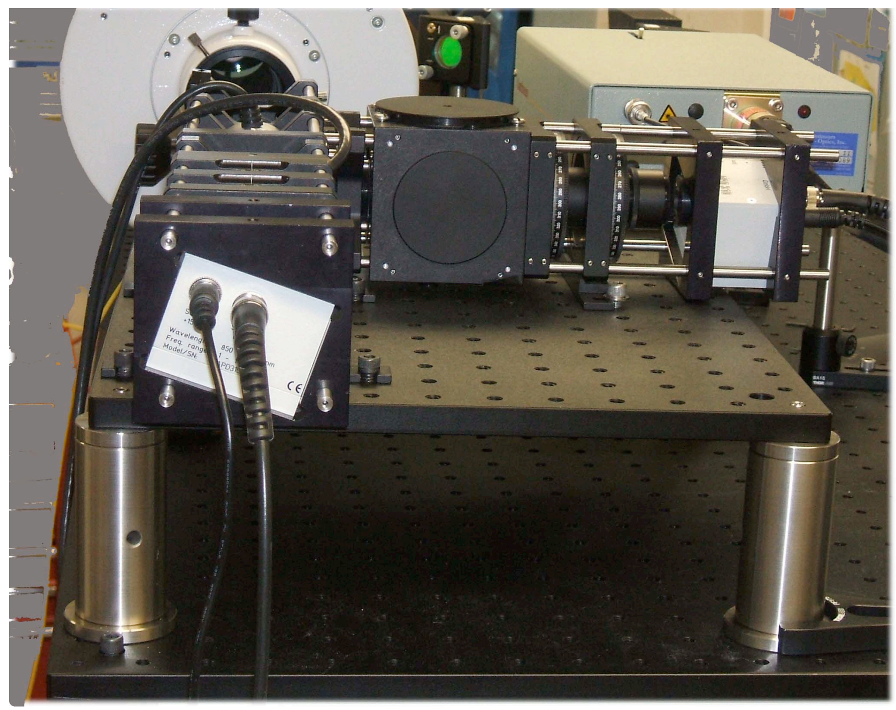
that will absorb light from this transmitter.

BROADBAND SYSTEM HARDWARE

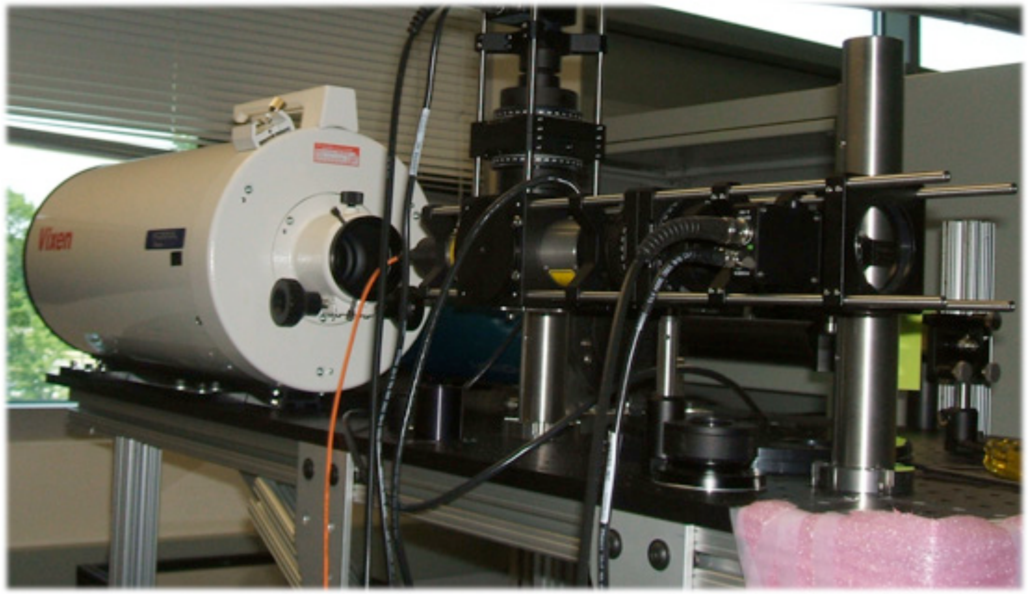


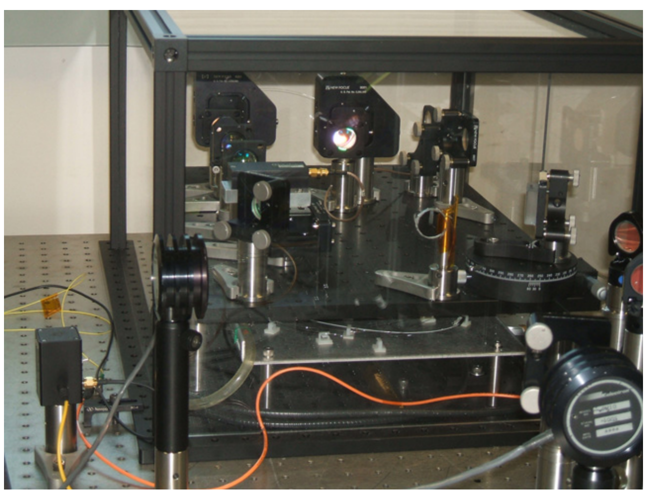


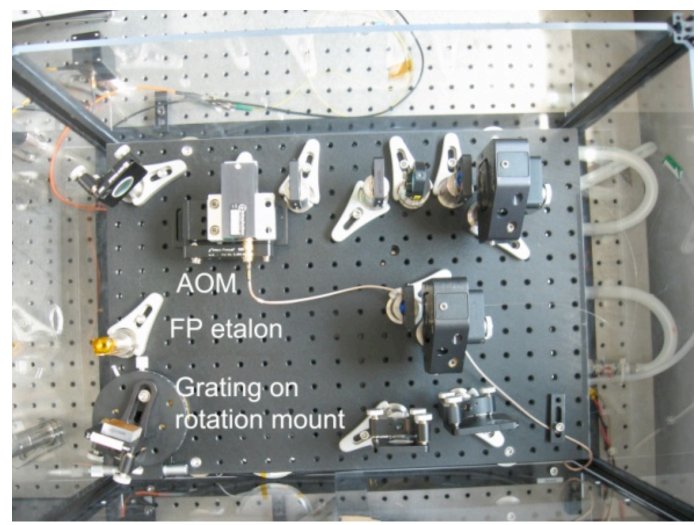




2.0 MICRON BROADBAND SYSTEM USING Tm FIBER LASER FROM NORTHROP GRUMMAN







Tm FIBER LASER IS INTRINSICALLY RUGGED AND HAS VERY HIGH ELECTRICAL TO OPTICAL CONVERSION EFFICIENCY

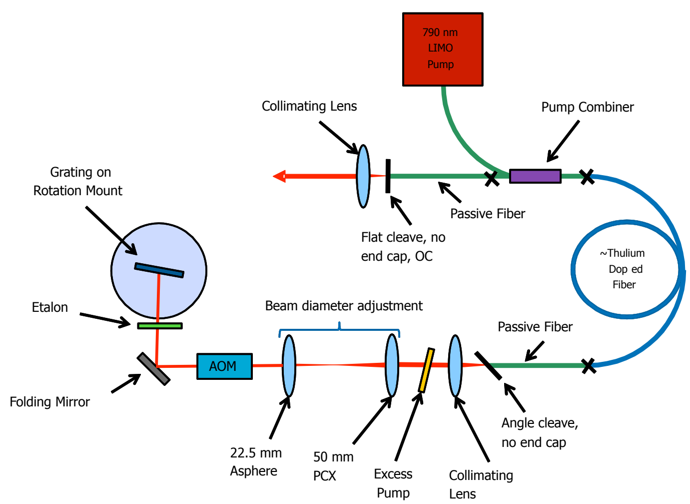
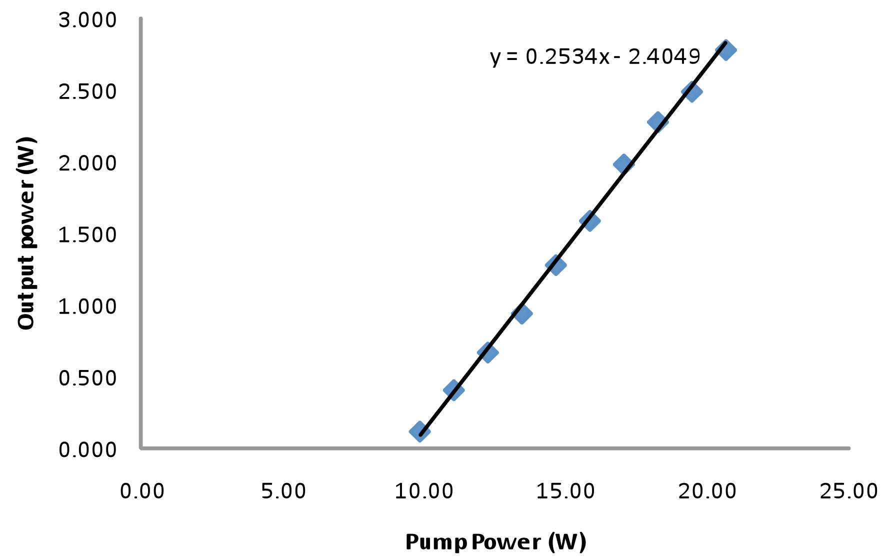
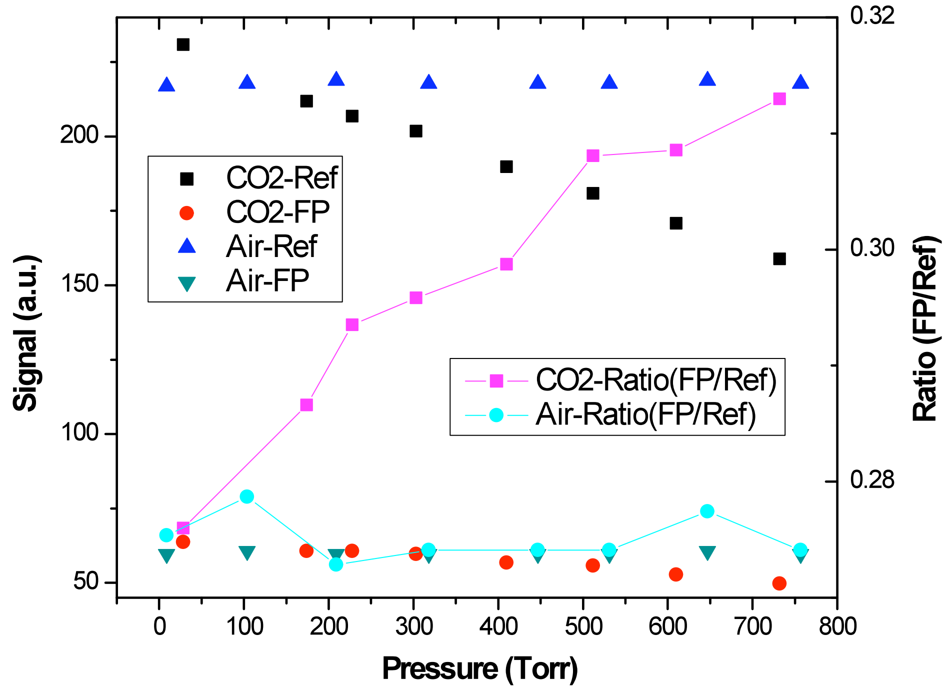


Figure 7: Schematic of current Tm fiber laser system



Current system produces 2.8 Watts

2 MICRON RECEIVER SHOWS GOOD SENSITIVITY TO CO2



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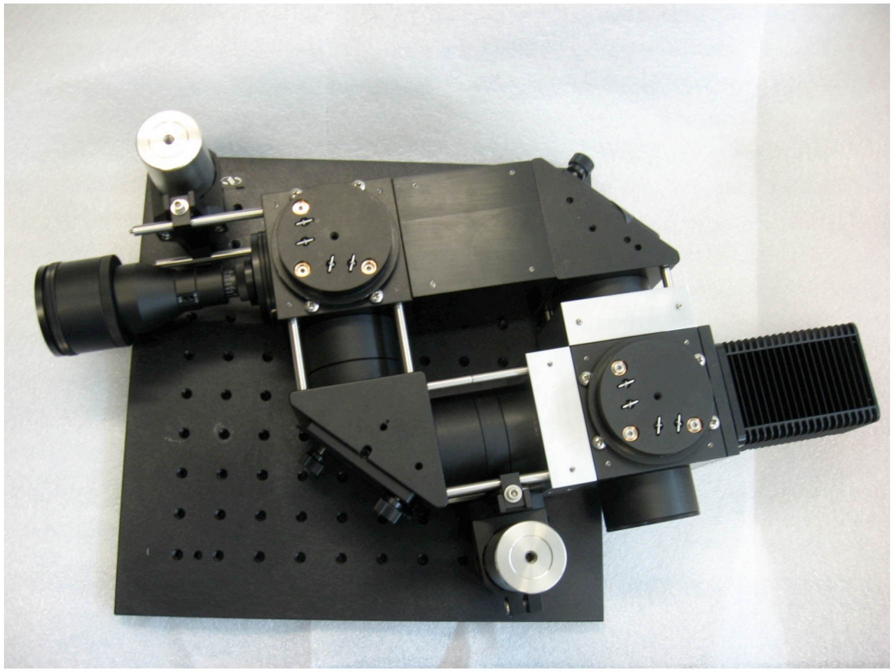
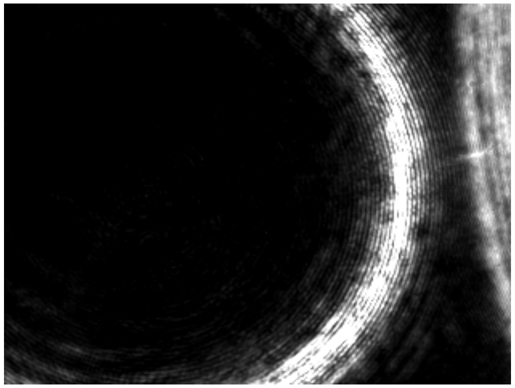
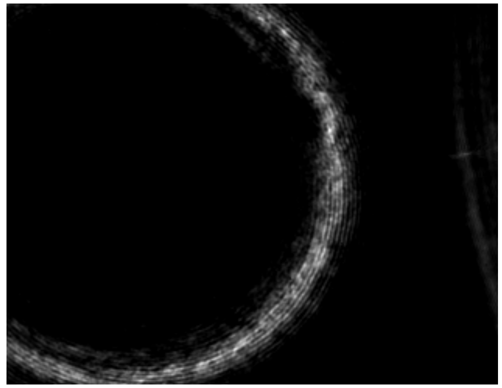
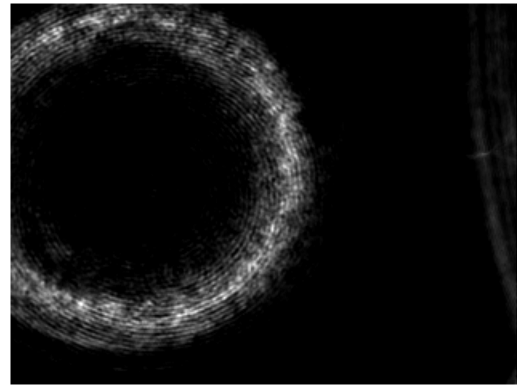
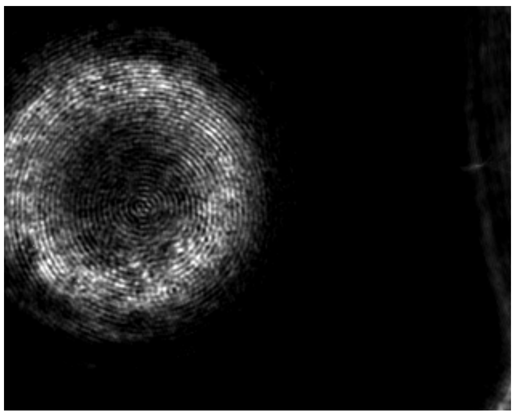


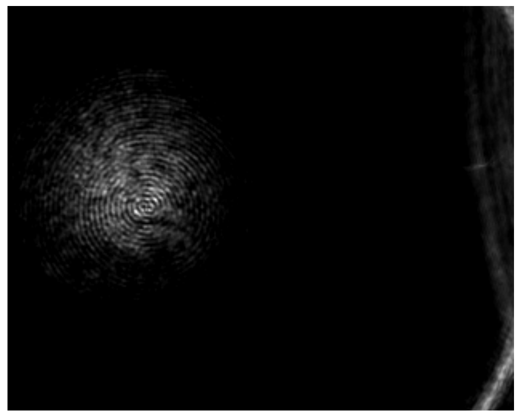
WAVELENGTH MAP OF FOCAL PLANE


1580.2nm


1580.6nm

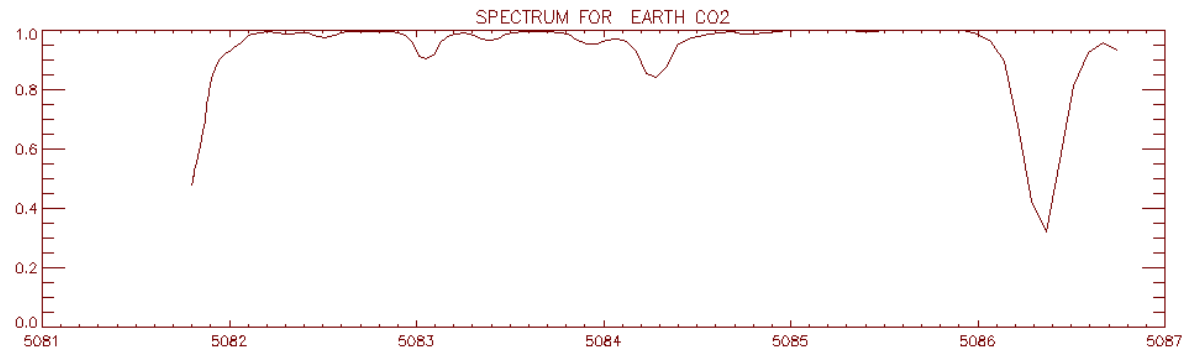

1580.9nm


1581.1nm

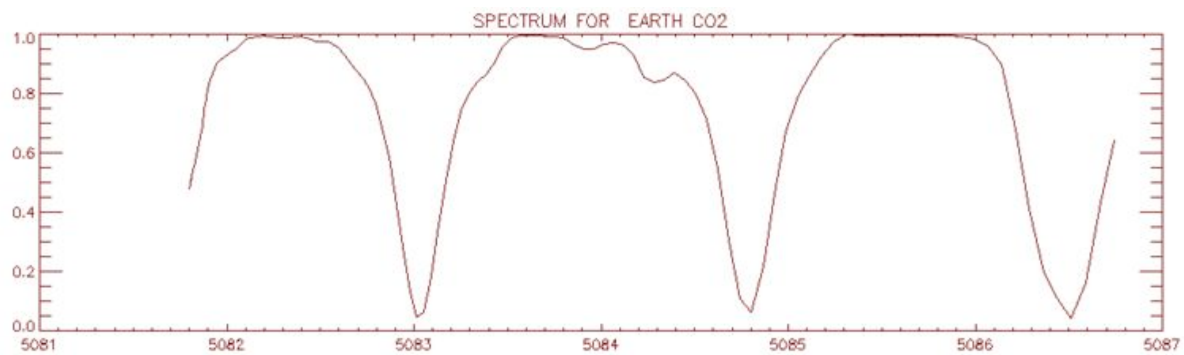

1581.3nm

Performance Simulation 2.0 micron lidar with array detector

Water vapor absorption 5000 ppm

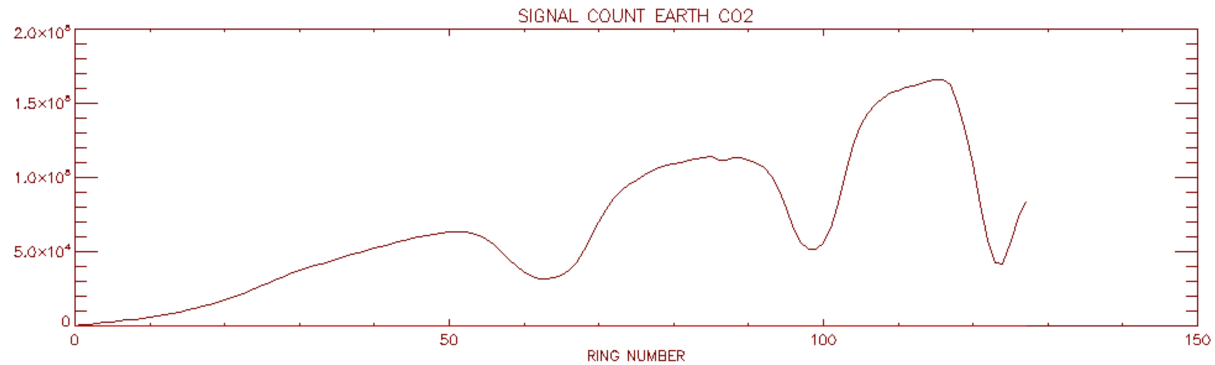


CO2 absorption 380 ppm

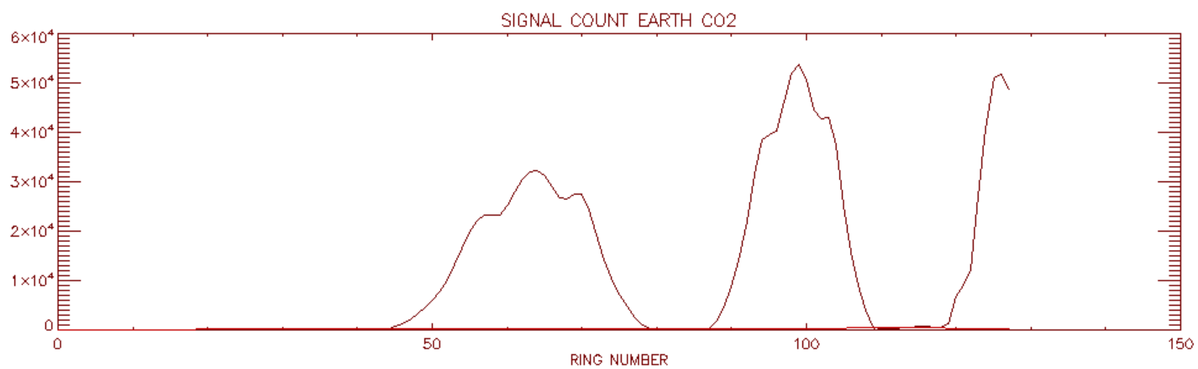


Performance Simulation 2.0 micron lidar with array detector

This is a plot of signal counts for each ring for an altitude of 1500 meters. FP spectrum is imaged on 128 x 128 array. 200 mW total laser power. 8 inch telescope.

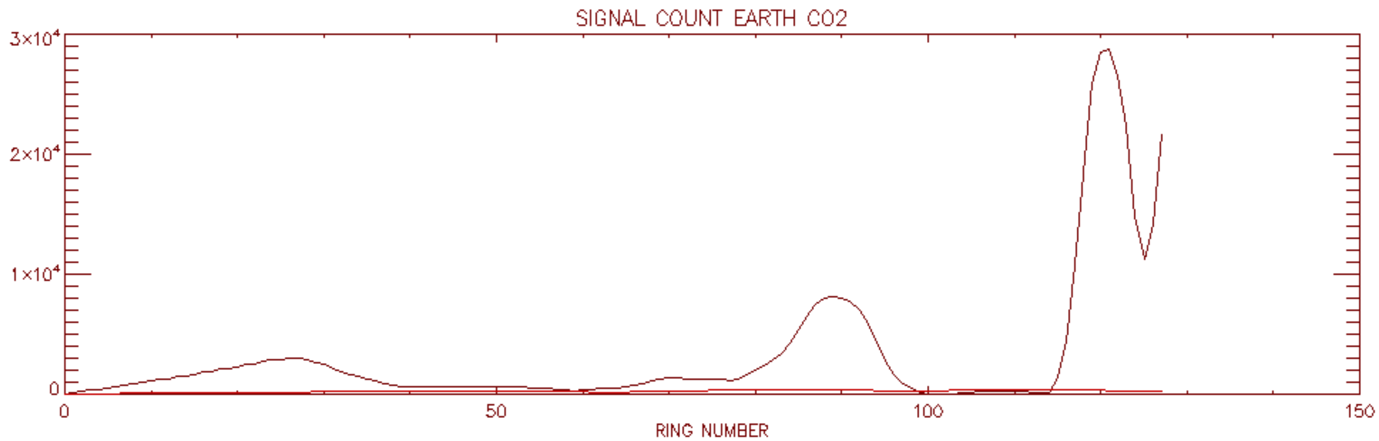


This is plot of change in ring counts for 380 ppm of CO2. Shot noise for each ring is also plotted. It's ~ 1000 counts.



Performance Simulation 2.0 micron lidar with array detector

Water vapor interference is small



This is change in ring counts for doubling of water vapor amount.

The one second SNR for CO_2 using pixels that are "sensitive" to CO_2 change is 786:1

Conclusions

- Innovative active system using advanced source technology development– will enable precise daytime or nighttime measurements of column CO_2

- Directly responds to NRC DS ASCENDS mission

- Number of lasers is reduced compared to competing technologies which reduces the complexity of sensor and thus the cost and risk of failure,

- Knowledge gained from previously developed passive sensor decreases the risk and cost of the present lidar system development

- The instrument can play a significant role as an intercomparison instrument for OCO (Orbiting Carbon Observatory) if it is rebuilt and launched as well as other laser based instruments under development for participation in ASCENDS.

Conclusions

- It can play a role as an airborne instrument in its own right in addressing the problems of scale arising from differences between point observations by the existing ground based CO_2 network and wider area measurements obtained by satellites

- Developed 2.0 micron broadband system as well and will compare performance of both systems to choose optimal approach for ASCENDS

- Have begun development of approach that uses array detectors instead of APD. This approach will have lower noise than APD and may simplify design of the detector optical train.

We wish to thank NASA's Earth Science Technology Office for its continued support and encouragement.